

## **A Brief Characterization of Gas Turbines in Combined Heat and Power Applications**

from

*Technology Characterization: Gas Turbines*  
Climate Protection Partnerships Division,  
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and

*Introduction to CHP Catalog of Technologies*

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EPA Combined Heat and Power Partnership Web site  
at

[http://www.epa.gov/chp/chp\\_support\\_tools.htm](http://www.epa.gov/chp/chp_support_tools.htm)

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## **Introduction and Summary**

Combined heat and power (CHP) refers to the strategic placement of electric power generating units at or near customer facilities to supply on-site energy needs. CHP enhances the advantages of distributed generation by the simultaneous production of useful thermal energy and electric power, thereby increasing the overall energy efficiency and offering environmental benefits over electric-only and thermal-only systems.

Gas turbines are currently the economic and environmentally preferred choice for new power generation plants in the U.S. They can be used in a variety of configurations, including CHP operations, which consist of a simple cycle gas turbine with a heat recovery heat exchanger to recover the heat in the turbine exhaust and convert it to a useful thermal energy, usually in the form of steam or hot water. Gas turbines are available in sizes ranging from 500 kilowatts (kW) to 250 megawatts (MW) and can operate on a variety of fuels such as natural gas, synthetic gas, landfill gas, and fuel oils. Most gas turbines typically operate on gaseous fuel with liquid fuel as a back-up. Gas turbines are one of the cleanest means of generating electricity, mainly because of their relatively high efficiency and reliance on natural gas as the primary fuel.

Many industrial and institutional facilities use turbines to generate electricity for use on-site. When used to generate power on-site, gas turbines are often used in CHP mode where energy in the turbine exhaust provides thermal energy to the facility. These CHP configurations are able to reach overall system efficiencies (electricity and useful thermal energy) of 70 to 80 percent. Gas turbines are ideally suited for CHP applications because their high-temperature exhaust can be used to generate process steam at conditions as high as 1,200 pounds per square inch gauge (psig) and 900 degree Fahrenheit or used directly in industrial processes for heating and drying. A typical commercial/institutional CHP application for gas turbines is a college or university campus with a 5 MW simple-cycle gas turbine. Approximately 8 MWth of 150 to 400 psig steam (or hot water) is produced in an unfired heat recovery steam generator (HRSG) and sent into a central thermal loop for campus space heating during winter months or to single-effect absorption chillers to provide cooling during the summer.

There were an estimated 40,000 MW of gas turbine based CHP capacity operating in the U.S. in 2000 located at over 575 industrial and institutional facilities.<sup>3</sup> Much of this capacity is concentrated in large combined-cycle CHP systems that maximize power production for sale to the grid. However, a significant number of simple-cycle gas turbine based CHP systems are in operation at a variety of applications (just under 10,000 MW total). Simple-cycle CHP applications are most prevalent in smaller installations, typically less than 40 MW. Forty percent of landfill gas CHP projects use gas turbines, based on the current LMOP database.

## **Performance Characteristics**

Table 1 (derived from Table 1 of EPA's *Technology Characterization: Gas Turbines*) summarizes performance characteristics for typical commercially available gas turbine CHP systems for 1 and 5 MW sizes (typical sizes for landfill gas use). Heat rates shown are from manufacturers' specifications and industry publications. Available thermal energy (steam output) was calculated from published turbine data on turbine exhaust temperatures and flows. CHP steam estimates are based on an unfired HRSG with an outlet exhaust temperature of 280 degrees Fahrenheit producing dry, saturated steam at 150 psig. The data in the table show that electrical efficiency increases as combustion turbines become larger. As electrical efficiency increases, the absolute quantity of thermal energy available to produce steam decreases per unit of power output, and the ratio of power to heat for the CHP system increases. A changing ratio of power to heat impacts project economics and may affect the decisions that customers make in terms of CHP acceptance, sizing, and the desirability of selling power.

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<sup>3</sup> PA Consulting Independent Power Database; Energy Nexus Group.

Footnote numbering is maintained from the original document.

**Table 1. Gas Turbine CHP - Typical Performance Parameters\***

Electricity Capacity	1 MW	5 MW
<b>Cost &amp; Performance Characteristics<sup>5</sup></b>		
Total Installed Cost (2000 \$/kW) <sup>6</sup>	\$1,780	\$1,010
Electric Heat Rate (Btu/kWh), HHV <sup>7</sup>	15,580	12,590
Electrical Efficiency (%), HHV	21.9%	27.1%
Fuel Input (MMBtu/hr)	15.6	62.9
Required Fuel Gas Pressure (psig)	95	160
<b>CHP Characteristics</b>		
Exhaust Flow (1,000 lb/hr)	44	162
GT Exhaust Temperature (Fahrenheit)	950	950
HRSG Exhaust Temperature (Fahrenheit)	280	280
Steam Output (MMBtu/hr)	7.1	26.6
Steam Output (1,000 lbs/hr)	6.7	25.0
Steam Output (kW equivalent)	2,080	7,800
Total CHP Efficiency (%), HHV <sup>8</sup>	68%	69%
Power/Heat Ratio <sup>9</sup>	0.48	0.64
Net Heat Rate (Btu/kWh) <sup>10</sup>	6,673	5,947
Effective Electrical Efficiency (%), HHV <sup>11</sup>	51	57

\* For typical systems commercially available in 2001

Source: Energy Nexus Group

<sup>5</sup> Characteristics for “typical” commercially available gas turbines generator system. Data based on: Solar Turbines Saturn 20 - 1 MW; Solar Turbines Taurus 60 - 5 MW.

<sup>6</sup> Installed costs based on CHP system producing 150 psig saturated steam with an unfired heat recovery steam generator.

<sup>7</sup> All turbine and engine manufacturers quote heat rates in terms of the lower heating value (LHV) of the fuel. On the other hand, the usable energy content of fuels is typically measured on a higher heating value (HHV) basis. In addition, electric utilities measure power plant heat rates in terms of HHV. The average heat content of natural gas is 1,030 Btu/scf on an HHV basis and 930 Btu/scf on an LHV basis - or about a 10% difference.

<sup>8</sup> Total CHP Efficiency = (net electric generated + net steam produced for thermal needs)/total system fuel input

<sup>9</sup> Power/Steam Ratio = CHP electrical power output (Btu)/useful steam output (Btu)

<sup>10</sup> Net Heat Rate = (total fuel input to the CHP system - the fuel that would normally be used to generate the same amount of thermal output as the CHP system output assuming an efficiency of 80%)/CHP electric output (kW)

<sup>11</sup> Effective Electrical Efficiency = (CHP electric power output)/(Total fuel into CHP system - total heat recovered/0.8); Equivalent to 3,412 Btu/kWh/Net Heat Rate.

Table 2 (derived from Table 3 of EPA’s *Technology Characterization: Gas Turbines*) details estimated capital costs (equipment and installation costs) for two typical gas turbine CHP systems. These are “typical” budgetary prices levels; it should be noted that installed costs can vary significantly depending on the scope of the plant equipment, geographical area, competitive market conditions, special site requirements, emissions control requirements, prevailing labor rates, whether the system is a new or retrofit application, etc. The cost estimates are based on systems that include DLE emissions control, unfired HRSG, fuel gas compression, water treatment for the boiler feed water, and basic utility interconnection for parallel power generation. There is no SCR system, no supplementary firing or duct burners, no building construction, and minimal site preparation and support.

Footnote numbering is maintained from the original document.

**Table 2. Estimated Capital Costs for Typical Gas Turbine-Based CHP Systems (\$000s)<sup>13</sup>**

<b>Nominal Capacity</b>		<b>1 MW</b>	<b>5 MW</b>
<b>Cost Component</b> (Thousands of \$)			
Equipment	Turbine Genset	\$675	\$1,800
	Heat Recovery Steam Generators	\$250	\$450
	Water Treatment System	\$30	\$100
	Electrical Equipment	\$150	\$375
	Other Equipment	\$145	\$315
Total Equipment		\$1,250	\$3,040
Materials		\$144	\$346
Labor		\$348	\$879
Total Process Capital		\$1,742	\$4,265
Project/Construction Management		\$125	\$304
Engineering		\$63	\$153
Project Contingency		\$87	\$215
Project Financing		\$129	\$316
Actual Turbine Capacity (kW)		1,210	5,200
<b>Total Plant Cost per net kW</b>		<b>\$1,781</b>	<b>\$1,010</b>

<sup>13</sup> Combustion turbine costs are based on published specifications and package prices. The total installed cost estimation is based in part on the use of a proprietary cost and performance model - SOAPP-CT.25 - (for state-of-the-art power plant, combustion turbine). The model output was adjusted based on Energy Nexus Group engineering judgement and experience and input from vendors and packagers.

Non-fuel operation and maintenance (O&M) costs presented in Table 3 (derived from Table 4 of EPA's *Technology Characterization: Gas Turbines*) are based on gas turbine manufacturer estimates for service contracts, which consist of routine inspections and scheduled overhauls of the turbine generator set. Routine maintenance practices include on-line running maintenance, predictive maintenance, plotting trends, performance testing, fuel consumption, heat rate, vibration analysis, and preventive maintenance procedures. The O&M costs include operating labor and total maintenance costs.

**Table 3. Gas Turbine Non-Fuel O&M Costs (Year 2000)**

<b>Electricity Capacity</b>		<b>1 MW</b>	<b>5 MW</b>
<b>O&amp;M Costs<sup>14</sup></b>			
Variable (service contract) (\$/kWh)		0.0045	0.0045
Variable (consumables) (\$/kWh)		0.0001	0.0001
Fixed (\$/kW-yr)		40	10
Fixed (\$/kWh @ 8000 hrs/yr)		0.0050	0.0013
<b>Total O&amp;M Costs (\$/kWh)</b>		<b>0.0096</b>	<b>0.0059</b>

<sup>14</sup> O&M costs are based on 8,000 operating hours expressed in terms of annual electricity generation. Fixed costs are based on an interpolation of manufacturers' estimates. The variable component of the O&M cost represents the inspections and overhaul procedures that are normally conducted by the prime mover original equipment manufacturer through a service agreement, usually based on run hours.

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